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Report on the Fact Finding Mission on the Management and Recycling of End-of-life Batteries used in Solar Home Systems in Myanmar

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AC	Alternating current
DC	Direct current
DRD	Department of Rural Development
ECD	Environmental Conservation Department
EIA	Environmental Impact Assessment
EMP	Environmental Management Plan
EPR	Extended Producer Responsibility
FLAB	Flooded lead-acid battery
JICA	Japan International Cooperation Agency
KfW	Kreditanstalt für Wiederaufbau
LAB	Lead-acid battery
LCO	Lithium-cobalt-oxide
LFP	Lithium-iron-phosphate
LMO	Lithium-manganese-oxide
LNCA	Lithium-nickel-cobalt-aluminium-oxide
LNMC	Lithium-nickel-manganese-cobalt-oxide
MMK	Myanmar Kyat
MONREC	Ministry of Natural Resources and Environmental Conservation
NWMSAP	National Waste Management Strategy and Action Plan
POPs	Persistent organic pollutants
PVC	Polyvinyl chloride
RoHS	Restriction of Hazardous Substances
SHS	Solar home system
ULAB	Used lead-acid battery
VRLAB	Valve-regulated lead-acid battery
WWF	World Wide Fund for Nature
YCDC	Yangon City Development Committee

Exchange rates

1 US$ = 1348.08 MMK

1 Euro = 1.181356 US$

Average internet exchange rates between 01.12.2017 and 14.12.2017

Source: www.oanda.com

Summary

Solar Home Systems (SHS) are a major means to provide electricity to the rural population of Myanmar. The Department of Rural Development (DRD) of the Ministry of Agriculture, Livestock and Irrigation in co-operation with the World Bank and KfW actively support SHS market penetration by providing SHS equipment to households. These subsidized systems are usually well designed units that follow certain quality standards for all components. Over the last years, declining purchasing prices for solar panels together with the consumer demand for charging mobile phones and to use electric lighting and possibly also TV, created strong incentives to purchase own SHS, even without government support. In contrast to subsidized SHS, these consumer SHS are mostly very rudimentary in terms of quality as they often lack suitable charge controllers and quality standards for PV panels and batteries. While both trends led to a remarkable SHS household penetration that is estimated to range between 30% and 50% of all off-grid households, this also has consequences for related waste volumes and end-of life management. In this context batteries are usually the first SHS component to fail: While battery life-times can range around 3-5 years and beyond, in particular the batteries of consumer SHS often have significantly lower life-times of around 1.5 – 2 years only. These short life-times are mostly due to the fact that consumers often opt for the cheapest available batteries, which are usually lead-acid batteries for automotive applications that are not designed deep discharges as they often occur with SHS. In addition, consumers often save the costs for a charge controller so that the used batteries are commonly exposed to uncontrolled charging and deep discharge.

Regarding battery technologies, lead-acid batteries are still the most commonly used type. Li-ion batteries are still too expensive for the consumer market in Myanmar and are therefore only used in some of the subsidized systems financed by the World Bank. In this context Li-ion batteries are favoured because of their superior life-time compared to lead-acid batteries. Nevertheless, there are still very limited experiences with the use of Li-ion batteries in SHS in Myanmar so that information on battery life-times are based on laboratory tests that do not necessarily reflect all real use conditions. Although future price developments of the various battery technologies are subject to various uncertainties, the last years have seen a steady decline in purchasing prices for Li-ion cells. If this trend continues, Li-ion batteries might become attractive for the SHS consumer market in Myanmar after 2020. Until this break-even point, the vast majority of SHS will continue to be equipped with lead-acid batteries.

Regarding waste volumes it is estimated that SHS-use generates between 11,500 t and 60,000 t of waste lead-acid batteries per year in Myanmar (average value: 36,000 t/a), which is above the volumes being generated by the automotive sector (between 17,000 t and 25,500 t per year with an average value of 21,000 t/a). In contrast, the volumes of waste Li-ion batteries from SHS are quite moderate with 29 t to 48 t of LMO batteries per year (average value: 38 t/a).

Waste lead-acid batteries are internationally classified as hazardous waste as they contain lead, lead-oxide as well as corrosive battery acid (sulfuric acid). Compared to the Li-ion batteries that are used in SHS (lithium-manganese-oxide (LMO) and lithium-iron-phosphate (LFP)), lead-acid batteries have a significant higher hazard potential.

On the other side, lead-acid batteries have a high material value and find various recycling markets within and outside Myanmar. Therefore, waste lead-acid batteries are commonly sold to scrap dealers and channelled to recycling enterprises. In contrast, Li-ion batteries (LMO and LFP) have a comparably low material value and meet limited demand on global recycling markets. In addition, transport logistics to Li-ion battery recycling facilities, which are currently only located in countries such as Belgium, Canada, USA and Germany, is complex and costly, adding to the difficult recy-

cling situation of such batteries. Subsequently it needs to be assumed that waste Li-ion batteries from SHS will not find their way to recycling but will be disposed together with household waste.

Battery technologies also differ in terms of fire safety aspects during the use phase: Although all battery types can be used in a safe with appropriate precautions, Li-ion batteries can be subject to so-called *thermal runaways* that can cause fires and explosions. Thermal runaways can occur with battery cells with production errors and/or with damaged cells (physical stress) and cells subject to overcharging and deep discharging. While Li-ion batteries used in SHS are usually not subject to extreme physical stress (normally encased in a box that is permanently placed indoors), it is very important that the batteries are protected by a well suited charge controller. Although subsidized SHS are always equipped with charge controllers, observations in SHS-using households revealed that many consumers manipulate their SHS and commonly bridge the charge controller. While this user habit may reduce the battery life-time of lead-acid battery, it creates fire risks when done with SHS using Li-ion batteries.

Research of the currently applied collection and recycling practices for lead-acid batteries revealed that consumers are well aware of the value of waste lead-acid batteries and that scrap dealers that exist in virtually all urban agglomerations purchase such batteries. These scrap dealers usually channel the collected batteries to various types of recycling enterprises, which can roughly be characterised as follows:

- Small refurbishing workshops who reassemble used batteries and sell them to the local market;
- Enterprises focusing on battery breaking and the sale of lead scrap and plastic cases for further recycling;
- Small scale lead smelters who reduce and smelt the lead in self-made furnaces;
- Two industrial lead smelters located in Myaung Da Kar Special Foundry Industrial Zone in Yangon (Yangon Metal Industry & MYSARCO).

Although this developed structure leads to quite intensive collection and recycling activities, there are considerable shortcomings that cause adverse impacts on human health and the environment in Myanmar. These shortcomings can roughly be summarized as follows:

- The battery acid is commonly drained into open ditches or to the soil at scrap yards where lead-acid batteries are collected. It is estimated that most battery acid is released to the environment uncontrolled, which is equivalent to 1,440 t to 7,515 t of acid from SHS batteries per year.
- Most of the applied battery breaking and recycling processes lead to the emission of lead and lead-oxide particles to the workspace and the environment. This involves the drainage of particles together with the battery acid (see point above), unsound transport and storage of damaged batteries and lead-scrap, unsound processes for breaking batteries, completely lacking off-gas treatment at small scale smelters, and unresolved disposal of slags at industrial smelters. Although no comprehensive survey was made to quantify these emissions, it is estimated that around 5% (between 374 t and 1,954 t) of the lead and lead-oxide contained in SHS batteries are emitted to the environment every year.

In order to reduce the negative impacts from end-of-life batteries from SHS, recommendations are given and classified in three fields of interventions: (1) Recommendations addressing the design of SHS, (2) steps to improve the recycling chain of lead-acid batteries, and (3) issues around developing a regulative framework and incentive system for sound management of e-waste:

1. For the design of SHS, it is recommended to introduce quality requirements for all parts of SHS to ensure durable and safe systems, in particular batteries. In addition, systems equipped with Li-ion batteries should have battery and charge controller integrated in one common housing clearly market with warning signs to avoid manipulation by users. Furthermore, it is recommended to use additional requirements for various SHS components to reduce the amount of embedded hazardous substances (e.g. minimize the use of lead in solder paste).
2. Generally, it is recommended to take action to improve the lead-acid battery recycling chain in Myanmar. Key steps in this direction are measures to increase awareness amongst decision-makers in policy and industry, the development of a roadmap for improvements, the training of auditors, baseline audits and improvement plans on a facility level, as well as follow-up activities including conformity assessment of recyclers and sanctioning of non-compliant players. In this context, it needs to be stressed that improvements largely depend on stringent government regulation and monitoring.
3. It is furthermore recommended to address the waste problems related to other SHS components within activities and efforts to organize a modern and effective e-waste collection and recycling system in Myanmar. Here it needs to be stressed that establishing a modern e-waste management system is a demanding task that usually requires the involvement of various authorities and stakeholders and usually takes several years from the start of related policy debates. Thus, related efforts by rural electrification projects should probably seek co-operation with other initiatives such as the ongoing consultation process related to the Hazardous Waste Management Masterplan.
4. In this context, one possible contribution of SHS initiatives could be pilot collection and recycling efforts: Such pilot activities could aim at the collection and sound recycling of a defined quantity of e-waste (e.g. the equivalent amount to the SHS equipment installed by a project). While such pilot activities can support the kick-start of sound collection and recycling activities, they can also provide important experiences and lessons-learned for e-waste related policy development.

1. Background & introduction

In Myanmar many rural households are not connected to the electricity grid. In order to achieve the Sustainable Development Goal No. 7 on affordable and clean energy, the Department of Rural Development (DRD) of the Ministry of Agriculture, Livestock and Irrigation is actively supporting the electrification of rural areas in Myanmar. This strategy is supported by the World Bank and KfW and is based on three pillars, namely electrification by network expansion, by mini-grids and by solar home systems (SHS). While this strategy is in many aspects successful, the deployment of SHS to rural areas also raised the concern that obsolete SHS equipment will sooner or later constitute an unresolved waste issue with adverse impacts on human health and the environment. This concern is particularly pronounced for the widely used lead-acid batteries that are – due to their contained hazardous substances – a particular severe threat to human and environmental health if not managed properly at the end of their service life. In this context, DRD and KfW assigned Oeko-Institut and Total Business Solutions to conduct a fact finding mission on waste batteries from SHS in Myanmar. The aim of this fact finding mission was to assess the current market and recycling situation for end-of-life lead-acid and lithium-ion batteries in Myanmar, and to develop ideas and concepts on how to improve the environmental and human health conditions in battery recycling in the country.

The fact finding mission was conducted by Mr. Andreas Manhart (Oeko-Institut e.V.) and Mr. Ko Latt (Total Business Solution Co. Ltd.) between 04th and 16th of December 2017 and involved visits to and interviews with key stakeholders involved in SHS distribution and use, as well as the collection and recycling of batteries. Visits and interviews particularly focused on the following stakeholder groups:

- Relevant national ministries (Ministry of Agriculture, Livestock and Irrigation, Ministry of Natural Resources and Environmental Conservation);
- Companies providing SHS to national electrification projects;
- Experts supporting project activities around SHS in Myanmar;
- Shops selling SHS equipment to private consumers;
- Villages and households using SHS (in Shan State);
- Regional government authorities (in Shan State) in charge of implementation of electrification projects and municipal waste management;
- Scrap dealers;
- Battery refurbishing workshops;
- Small, medium and large scale battery recycling enterprises.

A more detailed record of visits, interviews, names and contact details of involved stakeholders are provided in Annex I. This report contains the findings from the mission, which are partly completed by literature research. Chapter 2 elaborates on the current market situation of SHS in Myanmar, chapter 3 on the management of end-of-life batteries from SHS, chapter 4 on related environmental and health aspects and chapter 5 on safety risks. Chapter 6 then widens the scope to recycling issues related to other SHS components and chapter 7 on the regulatory framework for waste management and recycling. Final conclusions and recommendations are given in chapter 8.

2. Solar Home Systems in Myanmar

2.1. Market development and business models

In 2014, 67.6% of Myanmar's population lacked grid-electricity access and only around 200,000 households are newly connected to the grid annually (Department of Population of the Ministry of Labour, Immigration and Population 2017; World Bank 2015). With a total number of 10.9 million households of, this means that today an estimated number of 6.8 million households are not connected to the electricity grid in Myanmar. In this context, solar home systems (SHS) are recognised by the government of Myanmar as a key element of its National Electrification Plan and have seen a remarkable market penetration in rural areas over the last years.

Solar home systems are brought onto the Myanmar market mainly via two channels:

- Subsidized systems that are distributed within the framework of rural development efforts (in the following referred to as 'subsidized SHS');
- Systems rented or purchased on the open market by private consumers (in the following referred to as 'consumer SHS').

Most subsidized SHS are distributed by the Department of Rural Development (DRD) of the Ministry of Agriculture, Livestock and Irrigation. DRD is the implementing organisation of electrification projects financed by the World Bank and KfW, which both support the distribution of SHS in rural off-grid communities. Within the last years, 140,000 SHS have been distributed with World Bank financing in Myanmar (World Bank 2017) and it is planned to supply a total number of 456,500 households (2,282,500 people) with SHS until the end of 2021 under this scheme (World Bank 2015). No SHS have been distributed with KfW funding yet, but distribution will commence in 2018 with geographic focus on the Shan State. Besides the DRD implemented World Bank and KfW projects, subsidized SHS are also distributed by smaller projects and initiatives such as by the WWF and JICA. These projects are usually limited to up-to various hundreds of units each. All these projects have in common that SHS are either donated to households, or handed over at a highly subsidized price. In all cases, equipment ownership is fully transferred to the households.

Next to subsidized SHS, consumer SHS rapidly gained importance over the last years, mostly stimulated by falling prices for PV panels and the consumer demand to use and charge mobile phones in off-grid areas. According to Hamann (personal communication 2017), equipment purchase and ownership models are clearly dominating this market while other business models such as lease-to-own or ongoing-rental have not gained significant relevance on the SHS market in Myanmar.

The current market penetration of SHS systems is Myanmar is not known and the latest census data stem from 2014, which revealed that 945,242 households (8.7 % of all households) used solar power for lighting purposes (Department of Population of the Ministry of Labour, Immigration and Population 2017). Since that time market penetration significantly increased and today PV-panels are a very common sight in off-grid areas in Myanmar (see Figure 2-1). Interviews and visual observations in Southern Shan State suggest that in most off-grid villages various households make use of at least one SHS and very often refer to even two or three PV panels and several batteries. According to Hamann (personal communication 2017) comparable observations can be made in other off-grid areas of Myanmar. Thus, it can be estimated that around 30-50% of all off-grid households are equipped with one or more SHS.

Figure 2-1: PV panel for a solar home system in Shan State, Myanmar

Source: Own photograph

2.2. Common system specifications

Solar Home Systems consist of the following components:

- Photovoltaic panel;
- A charge controller;
- A battery;
- Electrical loads such as LED-lamps, DVD player or a TV[1].

[1] Electrical loads are in fact no integral part of a solar home system. Nevertheless, the number and types of loads strongly determine the required system specifications.

Depending on the type of electrical load, the power from the battery might have to be converted to another voltage (e.g. for charging mobile phones) or transformed into alternating current (e.g. for using an AC-powered TV). Thus, DC-to-DC converters and/or a DC-to-AC inverter might be additionally required. In Myanmar, most SHS are used for lighting purposes, as well as for charging mobile phones. Some SHS are also used to power either small DC video-players, or AC TVs. Table 2-1 gives an overview on component specifications recommended and sold by electrical equipment shops in Mandalay to private consumers planning to use the system for lighting, mobile phone charging, as well as TV (consumer SHS).

Table 2-1: Specifications and prices for a typical SHS sold to private consumers in Mandalay

Component	Specification	Purchasing price [MMK]	Purchasing price [US$]
PV panel	80 W	47,000	34.86
Controller	10 Ah	13,000	9.64
Inverter	300 W	39,000	28.93
Lead-acid battery	70 Ah	75,000	55.63
Total		164,000	121.65

Source: Own investigations

Nevertheless, field observations revealed that many users of consumer SHS do not make use of a controller, but charge the battery directly from the solar panel. Although this has almost inevitably negative implications for the life-time of the battery, the initial purchasing price for a SHS without a charge controller is lower. According to interviewed SHS users, such reduced systems that are only used for lighting and mobile phone charging (no inverter needed) are available for as cheap as 70,000 MMK (51.39 US$). The low purchasing price is also achieved by a comparably small automotive battery (40 Ah). According to interviewed SHS users, such a low-capacity battery together with the absence of a charge controller leads to battery life-times of only around 1.5 years[2].

SHS distributed within the framework of rural development projects (subsidized SHS) usually have the charge controller, the battery, DC-to-DC converters and possibly also the inverter integrated in one case (see Figure 2-2).

2 Interestingly, SHS users are very much aware of the short battery life-time of such SHS specifications. But instead of using a charge controller, households often decide to purchase a significantly larger and over-dimensioned lead-acid battery (e.g. 100 Ah truck battery) to achieve long battery life-times. Although this strategy is likely to be successful, it is associated with higher costs compared to the use of a charge controller.

Figure 2-2: Controller, battery and DC-to-DC converters integrated in one box

Source: Own photograph

Table 2-2 gives an overview of the technical specifications of World Bank financed SHS distributed by DRD through a first tender in 2015 and 2016. In total, around 140,000 of such systems have already been distributed in Myanmar. Another 95,000 systems are planned to be installed under a second tender starting in 2018 (World Bank 2017).

Table 2-2: Specifications of SHS distributed by DRD with World Bank financing

PV Panel	Number of LED lamps	Mobile phone charging	TV use
30 W	3	Yes	No
45 W	4	Yes	Yes
60 W	5	Yes	Yes

Source: Hamann (personal communication 2017)

The larger of these subsidized systems (those suitable to power 5 LED lamps, one TV and mobile phone charging) are available for around 300,000 MMK to 400,000 MMK (223 – 297 US$), including transport and installation in user household[3]. The higher price compared to the consumer system of Table 2-1 is explained by the use of deep-cycle LAB and quality requirements for SHS components.

2.3. User behaviour

Visits to three off-grid villages with various interviews and visits to SHS-using households gave an impression on some typical user behaviour relevant for battery volumes, their life-time and disposal. All these observations were made in households using SHS equipped with lead-acid batteries. In addition, subsidized SHS have been distributed in all three villages and therefore represent situations in which subsidized SHS and consumer SHS were used in parallel.

- As indicated in section 2.2, consumer SHS are often purchased, installed and used without charge controller, which is effectively reducing the life-time of the battery. Charge controllers have only been seen in subsidized systems.
- Users are used to connect batteries directly to the PV panel and often do this with clamps (in particular when using a consumer SHS). With these clamps users often charge more than one battery: After charging one battery for a few hours, another battery is connected. It was observed that in many households various lead-acid batteries were stored close to the place where the wires from the PV panel are entering the house (see Figure 2-3 and Figure 2-4).
- All users reported that the battery is typically the first component to fail. Only in some few cases and only in one village, some charge controllers failed earlier than the battery. In any case, all users reported that they usually try to fix the system by themselves. In case the battery reached its end-of-life, the old battery is transported to a scrap dealer in a nearby town (see chapter 3.1) and a new battery is purchased. In case the charge controller fails, the PV panel is directly connected to the battery to keep the system functional. Electrical engineers are rarely consulted as their service is often not available in off-grid villages and related to costs.
- Own repair operations are also done with subsidized SHS. In many households, the boxes of the subsidized SHS have been opened by the users to do own repairs or modifications (see Figure 2-4).
- To increase battery life-time, many consumers replace old batteries by bigger (oversized) batteries instead of buying a charge controller (section 2.2).

3 In these offers, also LED lamps, cables and mobile phone charging interface are included.

Figure 2-3: Consumer SHS without charge controller: batteries are directly connected to the PV panel using clamps

Source: Own photograph

Figure 2-4: Opened box of subsidized SHS

Source: Own photograph

2.4. Used battery technologies

Solar Home Systems in Myanmar are currently mostly equipped with lead-acid batteries (LABs). Lead-acid batteries are available as flooded lead-acid batteries (FLABs) where water has to be periodically refilled, and valve-regulated lead-acid batteries (VRLABs) which are maintenance free. Flooded lead-acid batteries are dominating the market for larger batteries (truck batteries), while valve regulated lead-acid batteries are quite common in the field of smaller batteries (car batteries, motorcycle batteries, batteries for small uninterruptible power supplies).

For stationary power storage such as for SHS, special deep-cycle lead-acid batteries have been developed. While automotive LABs are optimized for delivering short high-current burst to start the combustion engine, deep-cycle batteries are designed for regular deep discharges. For this purpose, deep-cycle batteries contain thicker active lead plates and therefore require more lead per battery. Deep-cycle VRLABs are used in most subsidized solar home systems that have been provided by DRD in co-operation with donors such as World Bank and KfW. While battery shops in Mandalay offer special solar batteries (see Figure 2-5), it is unclear whether these devices are real deep-cycle batteries or just conventional LABs with specific marketing for customers interested in SHS. In any case, interviews with shop owners and observations in off-grid villages in Southern Shan State suggest that the vast majority of SHS purchased on the free market (without project subsidy) use automotive LABs. Although automotive LABs usually have a shorter life-span when used in SHS when compared to deep-cycle batteries or Li-Ion batteries, the lower purchasing price (see Table 2-3), as well as the widespread availability seem to be reasons enough to opt for such batteries.

Figure 2-5: Lead-acid battery for the SHS market in Myanmar

Source: Own photograph

Lithium-Ion batteries are not extensively used in SHS in Myanmar and are not readily available on the local consumer market. Some SHS system providers started to use lithium-Ion batteries for projects and tenders with ambitious quality requirements. In this context, lithium-manganese batteries (LMO) are most commonly used, but still in limited numbers. Larger numbers have so far only been applied in SHS systems distributed by DRD under World Bank financing. According to Adhikari (personal communication 2017), 120,000 of such systems with LMO batteries have been distributed in Myanmar so far.

Lithium-iron-phosphate (LFP) are more expensive compared to LMO but can also endure more charging-cycles and have therefore longer life-times (Stahl et al. 2016). For this reason, LFP batteries are usually only used for project customers requiring a 3 year warranty period (Pyae Sone, Managing Director of Pro Engineering Co., Ltd, personal communication 2017). Other lithium-ion batteries such as lithium-nickel-manganese-cobalt-oxide (LNMC) and lithium-nickel-cobalt-aluminium-oxide (LNCA) are typically not used in stationary power storage as their primary characteristics are high energy densities, which is not a relevant factor for stationary power storage[4].

Table 2-3: Battery types and market prices in Mandalay (December 2017)

Battery type	Characteristic energy densities	Battery sub-type	Purchasing price for a 12 V and 65 Ah battery
Lead-acid	25–40 Wh/kg	Automotive FLAB	61,000 MMK (45.25 US$)
		Automotive VRLAB	75,000 MMK (55.63 US$)
		Deep-cycle VRLAB	92,000 MMK (68.25 US$)
Lithium-Ion	80–200 Wh/kg	LMO	163,000 MMK (120.76 US$)
		LFP	365,000 MMK (270.76 US$)

Source: Energy densities: Stahl et al. (2016), prices: Pyae Sone, Managing Director of Pro Engineering Co., Ltd, personal communication (2017) & own investigations

2.5. Battery volumes

To estimate battery volumes and market shares, the assumptions of Table 2-4 were made. Due to various uncertainties, this approach uses upper and lower values for various variables such as SHS market penetration, used battery capacities per household and battery life-time.

4 A high energy-density (which translates in comparably light and small batteries) is no selling argument for SHS in Myanmar. In contrast, it was reported by various interview partners that many SHS users in Myanmar prefer large and heavy batteries as these are the established and easy-to-test criteria for a (lead-acid) battery’s capacity.

Table 2-4: Data and assumptions used for calculating SHS battery volumes in Myanmar

Minimum estimate	Maximum estimate
6.8 million off-grid households (see section 2.1)	6.8 million off-grid households (see section 2.1)
30% of all off-grid households use SHS (see section 2.1)	50% of all off-grid households use SHS (see section 2.1)
On average one SHS-household uses one or more batteries equivalent to 12V 50Ah	On average one SHS-household uses one or more batteries equivalent to 12V 100Ah
LMO batteries are used in 120,000 households and have an average capacity of 50 Ah. All other households use lead-acid batteries.	Same as minimum estimate
The use of LFP batteries in SHS is negligible	Same as minimum estimate
Households using a SHS with LMO battery have no further battery in use.	Households using a SHS with LMO battery additionally use one or more lead-acid batteries equivalent to 12V 50Ah.
Average life-time of lead-acid batteries is 3 years.	Average life-time of lead-acid batteries is 2 years.
Average life-time of LMO batteries is 5 years.	Average life-time of LMO batteries is 3 years.
Specific weight of lead-acid batteries: 0.03 kg/Wh	Same as minimum estimate
Specific weight of LMO batteries: 0.002 kg/Wh (Stahl et al. 2016)	Same as minimum estimate

Source: Own assumptions

The assumptions of Table 2-4 were used to calculate the total battery volumes in use in SHS systems in Myanmar, as well as the resulting end-of-life volumes (see Table 2-5). For all further scenarios, the average values are used.

Table 2-5: Calculated SHS battery volumes

	Minimum estimate	Maximum estimate	Average
Lead-acid batteries in use in SHS	34,560 t	120,240 t	77,400 t
LMO batteries in use in SHS	144 t	144 t	144 t
Waste lead-acid batteries from SHS	11,530 t/a	60,120 t/a	35,820 t/a
Waste LMO batteries from SHS	29 t/a	48 t/a	38 t/a

Source: Own calculations

For interpretation of these figures, the following points have to be considered:

- As indicated by the significant differences between minimum and maximum estimate, the average values are subject to a high level of uncertainty that is caused by the various assumptions and the lack of a full market study.

- While the numbers in Table 2-5 give the impression of static values, battery volumes in use and generate battery waste volumes are subject to various influencing factors and vary over time.

Therefore, the figures of Table 2-5 should be seen as rough estimate indicating the order of magnitude rather than absolute volumes. Despite these limitations, the figures clearly indicate that battery volumes used in SHS in Myanmar are significant, both in terms of battery stocks in use, as well as waste batteries. It is notable that volumes of waste lead-acid batteries from SHS are probably above those from automotive applications, which generate between around 17,000 and 25,500 t per year (average value 21,000 t/a) (see Table 2-6).

Table 2-6: Lead-acid battery volumes in automotive applications in Myanmar

Vehicle type	**Registered number** (as of 06/2016)	**Estimated weight of used batteries**	**Batteries in use**	**ULAB volumes** (assumed life-time of 3 years)	**ULAB volumes** (assumed life-time of 2 years)
Private & passenger cars	505,649	20 kg	10,113 t	3,371 t/a	5,056 t/a
Buses (“Trawlergi”)	43,383	40 kg	1,735 t	576 t/a	868 t/a
Light duty trucks & other vehicles	257,329	40 kg	10,293 t	3,431 t/a	5,147 t/a
Heavy duty trucks	55,953	2 x 40 kg	4,476 t	1,492 t/a	2,238 t/a
Two & three wheelers	4,856,500	5 kg	24,283 t	8,094 t/a	12,141 t/a
Total				**16,957 t/a**	**25,450 t/a**

Source: Calculated with data from Road Transport Administration Department (without year) and Tür et al. (2016)

In total it can be estimated that Myanmar generates roughly around 60,000 t of waste lead-acid batteries per year: Around 36,000 t/a from SHS, 21,000 t/a from automotive applications and a non-quantified but smaller volume from other applications such as uninterruptible power supplies from IT-applications and back-up systems for critical infrastructure. In terms of lead volumes, this is roughly equivalent to 37,000 to 41,000 t/a. Although other economies such as China, Germany, Korea and Egypt have larger secondary lead quantities (China: 1,462,000 t/a; Germany: 290,000 t/a; South-Korea: 180,000 t/a; Egypt: 70,000 t/a) (ILA 2018; Tür et al. 2016), this volume is significantly above those of other developing such as Ghana and Kenya (both 23,000 t/a) (calculated with date from Atiemo et al. (2016) and Tür et al. (2016)).

2.6. Expected trends on the Myanmar battery market

As indicated in Table 2-3 purchasing prices for lead-acid batteries are currently significantly cheaper compared to those for Li-Ion batteries, which is the main reason for lead-acid batteries dominating the SHS-market in Myanmar. Li-Ion batteries are currently only used in subsidized systems with ambitious requirements for battery life-time.

Over the last years Li-ion technology has evolved quickly and it is a widely discussed question if and when Li-Ion batteries may become as cheaply available as lead-acid batteries. Taking into account the data of Table 2-3, the prices for LMO batteries will have to go down by 45% to be in the same range as deep-cycle lead-acid batteries. It is assumed that beyond this break-even point of purchasing prices a widespread shift to Li-Ion batteries in developing countries as Myanmar may occur.

Lead-acid batteries are a mature technology with established production technologies and capacities. The only relevant factor influencing battery purchasing prices is the world market price for lead, which has been quite stable over the last years. Therefore, it is assumed that prices for lead-acid batteries will be stable over the next years.

In contrast, the development of Li-Ion battery prices depends on two factors that are both subject to trends over time:

- Expansion of production capacities and the use of economies of scale;
- Price development of raw materials required for battery production.

While the first factor is likely to lead to a continuous reduction of production costs, the second factor points into the opposite direction as world market process for battery raw materials (in particular lithium and cobalt[5]) have seen significant increases over the last year (Nelson 2017). In this context, price developments for Li-Ion batteries are difficult to predict, but market analysts suggest that battery prices (at least for cobalt free types) will continue to fall over the next years as prices for Li-Ion batteries have constantly been reduced by an average of 20% per annum between 2010 and 2016 (Curry 2017). Assuming that this trend will continue at the same rate, the break-even point between Li-ion batteries (LMO-type) and lead-acid batteries will be reached in 2020 in Myanmar. Due to the various uncertainties of this prognosis, this date should only be interpreted in a way that a massive market shift to Li-ion batteries in SHS will not occur before 2020 in Myanmar. An interviewed local market observer even suggests that lead-acid batteries will continue to dominate the Myanmar SHS market for at least 5 more years (Pyae Sone, Managing Director of Pro Engineering Co., Ltd, personal communication 2017).

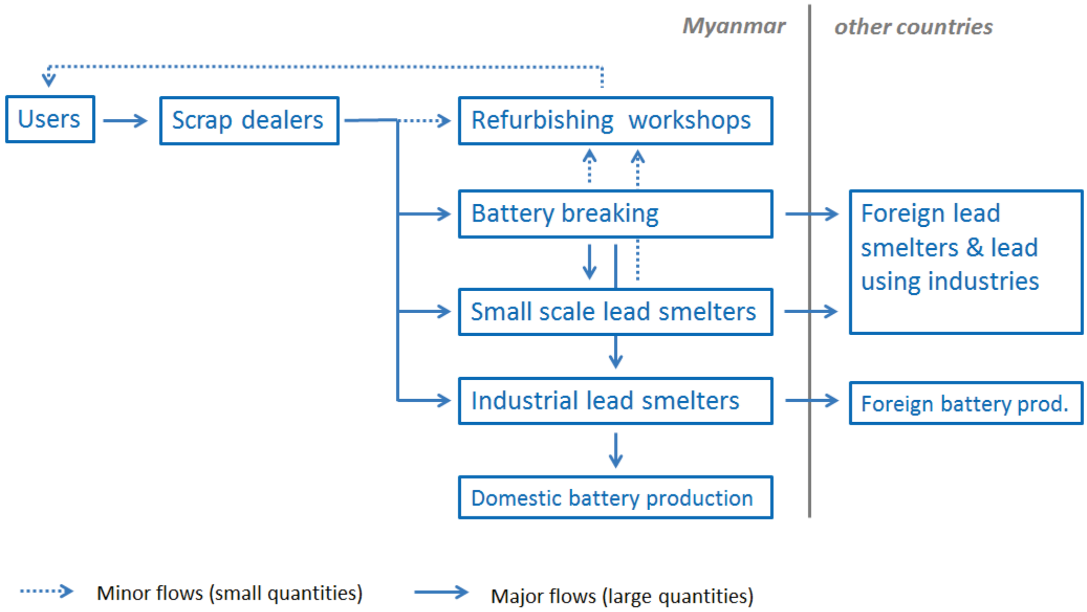
3. Management of end-of-life batteries from solar home systems

3.1. Lead-acid batteries

An overview on the flows of end-of-life lead acid-batteries in Myanmar is given in Figure 3-1. The flows do not only apply to waste lead-acid batteries from SHS, but also to batteries from other applications, most notably vehicles (car, trucks, motorcycles). The individual management steps are described in the following sections.

[5] For the battery types relevant for SHS in Myanmar no cobalt is required (see section 2.4). Thus, the price development of cobalt is not relevant for this application.

Figure 3-1: Flows of end-of-life lead-acid batteries in Myanmar



Source: Own graphic

3.1.1. Disposal habits of users

Due to their high lead contents, waste lead-acid batteries have a positive market value in most parts of the world, including Myanmar. One interviewed scrap dealer reported that he gets 1,700 MMK (US$ 1.26) per kilogram of waste lead-acid batteries (without acid) from a larger trader. Part of this money is used to buy waste lead-acid batteries from consumers. As indicated in section 2.3 users of SHS are well aware of this value and commonly bring their old batteries to scrap dealers in nearby towns. All interviewed SHS users knew at least one scrap dealer in a nearby town that buys waste lead-acid batteries (see section 3.1.2). All users reported to sell their waste batteries without prior draining of the battery acid.

3.1.2. Scrap dealers

Scrap dealers can be found in all urban agglomerations in Myanmar. Typically, such scrap dealers buy, collect, sort and sell recyclable waste such as cardboard, bottles, ferrous metals and aluminium scrap (see Figure 3-2). Various scrap dealers have been interviewed and all of them are buying and collecting waste lead-acid batteries. Suppliers are typically remunerated on the basis of a battery's size or weight.

Figure 3-2: Impressions from scrap dealers in Shan State

Source: Own photographs

Scrap dealers usually pass-on their collected batteries to scrap dealers specialized in waste lead-acid batteries. Such specialized dealers typically have warehouses in larger towns and also remunerate deliveries on the base of the batteries' weight. Here it is noteworthy to mention that these specialized traders only remunerate the weight of the dry batteries. To do so, all batteries either have to be delivered drained, or are drained upon reception. FLABs are drained by opening one or more plugs and VLABs are drained by punching holes into the case using a knife and a hammer (see Figure 3-3). The acid is commonly drained into the soil or public sewages. Only one of the interviewed scrap dealers collects some of the acid to pass it on to battery refurbishers for reuse (see section 3.1.3). Waste batteries are either sold to battery breaking enterprises (see section 3.1.4), to small scale lead smelters (see section 3.1.5), or industrial lead smelters (see section 3.1.6). In the latter case, batteries are usually sold to an agent who organises the transport to the smelters in Yangon. Small quantities of batteries (usually FLABs that appear to be in a comparably good state) are also sold to local battery refurbishers (see section 3.1.3).

One of the visited scrap dealers was also involved in battery breaking operations, in particular of small batteries (mostly from motorcycles). These activities are in-line with those descripted in section 3.1.4.

Figure 3-3: Draining of lead-acid batteries at one scrap dealer in Mandalay

Source: Own photograph

3.1.3. Refurbishing workshops

One battery refurbishing workshop was visited in Mandalay. The workshop is located in a residential building in a residential neighbourhood (see Figure 3-4). The owner is the only person working in the workshop. This refurbishment workshop receives waste truck batteries and used battery acid from a nearby scrap dealer (see section 3.1.2). The battery is opened and lead plates are taken out. Cases and plates are cleaned and damaged plates are replaced by other plates that are either taken from other waste batteries or specifically produced for this purpose (see section 3.1.4). The plates are placed back in the case and connected by using molten lead as solder paste (see Figure 3-5). The battery is closed by gluing the top cover onto the battery case. After being filled with recycled electrolyte, the batteries are charged (see Figure 3-5) and sold to consumers with a warranty of 1 year.

Although it is reported that such battery refurbishment workshops are operating in many parts of Myanmar, their operations are likely to absorb only a relatively small portion of end-of-life batteries in Myanmar. Nevertheless, their activities can have quite substantial negative health implications – in particular in densely populated settings (see chapter 4).

Figure 3-4: Building hosting the visited battery refurbishing workshop

Source: Own photograph

Figure 3-5: Inside the refurbishing workshop: Lead melting for solder paste (left), charging of refurbished batteries (right)

Source: Own photographs

3.1.4. Battery breaking

Although small and industrial lead smelters have own battery breaking operations (see sections 3.1.5 and 3.1.6), there are also battery breaking companies without own smelting operations. Both visited battery breaking facilities were mainly specialised on the breaking and dismantling of small motorcycle batteries. Apparently, the reason for this specialization is the lack of related breaking capacities in the established smelters in Myanmar. The batteries are first opened by using a machine shearing-off the batteries' top covers (see Figure 3-6). The subsequent extraction of lead scrap is done manually with simple tools. The lead scrap is packed in sacks and passed-on to domestic smelters or exported. The plastic cases are given to domestic plastic recycling companies. The plastic cases are sold unwashed, giving rise to the concern that lead residues might lead to cross-contamination into other applications.

Both companies are also active in recovering lead-plates for reuse. One of the facilities also had some small smelting equipment to cast new lead plates for battery refurbishing enterprises (see Figure 3-7).

The observed operations made a very crude impression: Workers were not equipped with appropriate personal protection equipment and the processes were arranged in a way that emissions of lead particles and acid to the environment are almost inevitable. Further concerns are ergonomic issues in the working environment (workers are sitting/squatting on the ground for their tasks), potential sources for accidents (unprotected machines for battery breaking), as well as the absence of any appropriate sanitary facilities.

Figure 3-6: Facility specialized on the breaking of small lead-acid batteries

Source: Own photograph

Figure 3-7: Recovered lead-plates for reuse (left) and workshop to cast new lead plates (right)

Source: Own photographs

3.1.5. Small scale lead smelters

There is one small scale lead smelter located outside of Mandalay. As indicated by the owner of this smelter, there have been eight such facilities in and around Mandalay until recently, but seven of them have been shut-down by the local authorities for pollution concerns. The one remaining smelter was not shut down because it is located in some distance from inhabited areas. The facility uses five self-made blast furnaces fired with charcoal (see Figure 3-8). By order of the Mandalay authorities, the furnaces are only allowed to be operated at night-time between 6pm and 3am. Each smelter can produce around 320 kg of lead per night-shift. Thus, the maximum monthly capacity of the facility is 48 metric tonnes of lead output.

The smelter is owned and run by one man who took over the business from his father. According to the owner, the facility was established 25 years ago in this location. In addition to the owner some few people were observed working on the compound (preparing clay for the furnaces).

Most activities (battery breaking, smelting…) are carried-out under simple roofed structures to be sheltered against rainfall. Batteries are opened using a battery guillotine. As the whole facility is not connected to the electricity grid, a diesel generator is used to power the machine. Although battery acid is captured under the machine, it is later drained to the soil of the nearby environment[6]. Plastic cases are washed and sold to plastic recyclers. The exact washing process could not be identified during the visit, but it seems likely that waste water (including lead contamination) is released to the environment.

6 It is assumed that most batteries have already been drained prior to delivery as this is a common habit in the supply-chain of waste lead-acid batteries in Myanmar (see section 3.1.2).

Figure 3-8: Furnaces of a small scale smelter close to Mandalay

Source: Own photographs

Grid separators are sorted-out from the lead scrap and disposed uncontrolled in the nearby bush. Also battery cases from unconventional polymers are disposed in this manner. The recovered lead scrap is processed in the described furnaces (also see Figure 3-8). The furnaces are charged through an opening in the lower part of the stack. With this charging, the lead scrap is placed on top of the charcoal fire and molten lead is accumulating at the bottom of the furnaces. The liquid lead is scooped from the furnace with a long ladle manually. The lead is casted into bowls giving the ingots a distinct lenticular shape. Slags from the smelters are collected, milled and reintroduced into the furnace. There is no off-gas treatment.

Despite the crude nature of processing steps, the central part of the facility made a very orderly impression with swept ground and various religious decorations. Nevertheless, it is obvious that the applied processes necessarily lead to significant emissions of lead and sulphur into the environment. Taking into account the many years of operation, it is very likely that the place and its vicinity are highly contaminated.

Figure 3-9: Battery guillotine (left) and disposal of grid separators (right)

Source: Own photographs

Although this smelter is apparently the only remaining facility of this type in the Mandalay region, it is not known if and how many such plants are operating in other parts of the country.

3.1.6. Industrial lead smelters

There are currently two industrial secondary lead smelters in Myanmar:

- Yangon Metal Industry Co., Ltd
- Myanmar Smelting & Refining Co., Ltd (MYSARCO)

Both facilities are located in the Myaung Da Kar Special Foundry Industrial Zone in Yangon. While the facility of Yangon Metal Industry was very transparent regarding this fact finding mission and enabled a guided visit to all parts of the facility, the smelter of MYSARCO could – despite various related requests – not be visited. A meeting with the company management on 15.12.2017 did not yield much significant information on the company's environmental performance and working conditions and gave the impression that the management is deliberately shielding-off its facility from potentially critical visitors.

Yangon Metal Industry is a Myanmar owned company and belongs to the Proven group that also has a factory for lead-acid battery production (branded as "Toyo" batteries). The company started ULAB recycling in 1996 in another location but relocated in 2011 to the current site. Formerly, the current site was occupied by the battery production facility, which is today located in another area of Yangon. The company employs 85 permanent workers in the recycling plant and around 100 persons in the company's efforts to buy and collect ULABs throughout Myanmar.

MYSARCO set-up its facility in 2015 and started smelting operations in 2016. It is an Indian investment but does not belong to any other company or group of companies.

Both smelters recycle ULABs and lead scrap (mostly from ULABs, but also from applications such as fishing gear) sourced in Myanmar and produce refined lead of a minimum purity of 99.97%, as well as lead alloys to be used in domestic or international battery production. While Yangon Metal Industry passes-on a part of its lead and alloy production to its battery production facility, MYSARCO exports all its lead products to foreign destinations. Yangon Metal Industry has a monthly capacity of 2,500 t of dry ULABs and lead scrap and MYSARCO 3,000 t respectively. Assuming a total ULAB generation of 60,000 t/a in Myanmar (see section 2.5), which is roughly equivalent to 53,000 t of dry batteries, this means that the two facilities have the capacities to treat between 100% of the countries ULAB volumes, not including the battery acid. As both smelters usually operate at around 70% of its capacity, the real market share of ULABs being recycled at the two smelters is estimated to be in a range between 75% and 80%.

The management of MYSARCO reported that the company has plans to also venture into other metal scrap recycling fields such as aluminium, copper and brass.

For the above mentioned reasons, a more detailed plant assessment could only be done for Yangon Metal Industry, which is shortly summarized here:

The visited secondary lead smelter of Yangon Metal Industry is in most parts a modern and well managed facility. The equipment used for smelting and off-gas treatment is up-to date and well maintained (see Figure 3-10). The core part of the facility – the lead smelting and refining area – made a clean and orderly impression. Workers were mostly equipped with appropriate personal protection equipment. The recorded blood lead levels of workers show that emission control and industrial hygiene measures are widely effective. In total, it can be confirmed that the company has a developed safety and improvement culture.

Figure 3-10: Rotary furnace installed and used at Yangon Metal Industry

Source: Own photograph

Nevertheless, there are three major weaknesses that will need to be addressed by the company before it can be recommended as a preferred disposal option for waste lead-acid batteries in Myanmar:

- The battery storage area is insufficient as delivered batteries and lead scrap are stored in the open and without protection against rainfall, wind and unintended acid leakages. Some batteries and lead scrap were even stored on unsealed ground, which makes a proper cleanup of dust and debris difficult to impossible.
- The facility does not have any installation to capture and treat battery acid. Although the management argues that all batteries are delivered without acid and that this is common practice in Myanmar, it must be assumed that the current purchasing practice of buying only dry batteries is the major reason for this habit of acid drainage in the supply chain. Yangon Metal Industry has to upgrade its facility in this regard and interact with its suppliers to deliver ULABs with acid. In this context, it is noteworthy that ULAB acid could quite easily be purified and used in the production of new lead-acid batteries of the Proven Group. This measure would not only benefit the environment, but also reduce the corporate expenditures for new electrolyte.
- The company does not have a sound solution for the slags. The slag is currently stored awaiting future solutions. This issue is further aggravated by the fact that lead contents of slags are quite pronounced and by the current storage practice that does not effectively prevent the material from rainfall and wind.

Further improvement potential exists in the housekeeping of the battery-breaking area (avoid leakages of acid and process water), the sanitary facilities (installation of showers, mandatory change of clothes and use of showers before entering the canteen and after the end of every shift) and the frequency of blood-lead tests (should be done at least half-annually). Further improvement potentials might exist, which have not been identified due to the limited nature of the visit.

A more comprehensive description of the findings and recommendations related to Yangon Metal Industry can be found in Annex II.

3.2. Li-Ion batteries

As the application of Li-ion batteries in SHS in Myanmar is a rather new and still limited development (see section 2.4), these batteries have mostly not yet reached their end-of-life. Thus, this section will elaborate on likely future end-of-life management patterns for Li-ion batteries from SHS in Myanmar, drawing from findings from current waste management structures, as well as general considerations on the material value and recycling of Li-ion batteries

3.2.1. Li-ion recycling activities in Myanmar

Various interviews with scrap dealers and recycling enterprises revealed that Li-ion batteries are currently not in the scope of the formal or informal Myanmar recycling industry. None of the interviewed scrap dealers and recyclers was aware of any option to sell waste Li-ion batteries at a profit. Subsequently, none of the scrap dealers and recyclers had any waste Li-ion batteries in stock or was interested in collecting / buying such batteries. One exemption were waste pickers at the municipal dump site of Taunggyi (Shan State), who showed a small amount of collected Li-ion batteries from mobile phones and electric mosquito swatters (see Figure 3-11). The waste pickers claimed to be able to sell these batteries to a local shop in town. No further information could be retrieved and it is assumed that this activity happens in the context of reuse and repair activities.

Figure 3-11: Li-ion batteries at the municipal dump site in Taunggyi

Source: Own photograph

3.2.2. International context

While the absence of significant collection and recycling efforts in Myanmar can partly be explained by the modest volumes of end-of-life Li-ion batteries, this pattern is also a consequence of the limited material value, the limited global recycling capacities and the management challenges of such waste batteries:

- In contrast to lead-acid batteries which have an average concentration of lead and lead-alloys of around 65% (Stahl et al. 2016; Tür et al. 2016), the concentrations of recyclable materials such as lithium, nickel and cobalt are quite small in many Li-ion batteries: While Li-concentrations are typically below 10%, nickel and cobalt are not used in LMO and LFP-cells at all (those cells that are used in Li-ion batteries for SHS – see section 2.4). This leads to a situation where the costs for the recycling of some Li-ion batteries is exceeding the economic value of the recovered materials (Batteries International). While cobalt containing Li-ion batteries (lithium-cobalt batteries, lithium-nickel-cobalt-aluminum batteries, lithium-nickel-manganese-cobalt batteries) achieve positive scrap market prices ranging between 180 and 2,200 US$/t (Rockaway Recycling 2017), there are currently no related positive offers for LMN and LFP batteries.
- Due to the complex material composition of Li-ion batteries, recycling is a complex process and global capacities are still very limited. There are currently only very few companies that can recycle Li-ion batteries on an industrial scale. Such plants currently exist in Belgium (Umicore), USA (Retriev Technology), Canada (American Manganese), Germany (Accurec) (Harvey 2017).
- Storage and transport of waste Li-ion batteries raise various issues around fire safety, which are further described in section 5.2. For these reasons, shipments to recycling facilities are associated with significant efforts and costs.

4. Environmental and health aspects of battery recycling & disposal practices

Batteries commonly contain materials with a high environmental relevance for the end-of-life phase. Emissions of such substances usually do not occur during the intended use of the batteries as materials are usually well encapsulated. But this encapsulation is commonly destroyed or removed during the end-of-life phase (recycling) so that hazardous materials might be brought in contact with humans and the environment. In addition, user behavior as illustrated in section 2.3 may also lead to emissions of certain substances during the use-phase, e.g. in relation to thermal runaways (see section 5.2).

Generally, battery cells consist of various substances with very specific hazards for human health and the environment. In the following, the hazard potential of battery types is presented on the basis of hazard statements of the various contained materials. These hazard statements can be attributed with so-called *impact factors* (German: *Wirkfaktoren*) that indicate the severity of possible impacts on health and the environment. These impact factors can range between 1 and 50,000: The higher the severity of potential impacts, the higher the factor (Bunke 2003; Oltmanns et al. 2016). Table 4-1 presents an overview of the hazard statements and impact factors of some materials used in lead-acid batteries and Li-ion batteries (only LMO and LFP).

Table 4-1: CAS hazard statement and impact factors of some materials used in lead-acid and li-ion batteries

Battery type	Material	CAS-No.	Hazard statement	Impact factor
Lead-acid	Lead / lead alloys (Pb) Lead monoxide (PbO) Lead-dioxide (PbO2)	7439-92-1 1317-46-8 1309-60-0	H360FD May damage fertility. May damage the unborn child.	1,000
			H362 May cause harm to breast-fed children	100
			H372 Causes damage to organs through prolonged or repeated exposure	500
			H410 Very toxic to aquatic life with long lasting effects	50,000
	Sulfuric acid	7664-93-9	H314 Causes severe skin burns and eye damage	100
Lithium-ion	LiMn2O4	39457-42-6	No entry found	-
		12057-17-9 (alternative)	H302 Harmful if swallowed	10
			H332 Harmful if inhaled	10
			H413 May cause long lasting effects to aquatic life	1,000
	LiFePO4	15365-14-7	None	-
	LiPF6	21324-40-3	H301 Toxic if swallowed	100
			H314 Causes severe skin burns and eye damage	100
			H372 May cause damage to organs through prolonged or repeated exposure	500
	C3H4O3	96-49-1	H302 Harmful if swallowed	10
			H319 Causes serious eye irritation	50
			H373 May cause damage to organs through prolonged or repeated exposure	50
	C3H6O3	616-38-6	H225 Highly flammable liquid and vapour	-
	Graphite / carbon	7440-44-0 7782-42-5	None	-
	CLi2O3	7439-93-2	H302 Harmful if swallowed	10
			H319 Causes serious eye irritation	50

Source: Graulich & Manhart (2017); Stahl et al. (2016)

Table 4-1 indicates that all battery types contain various materials subject to one or more hazards for human health and the environment. Stahl et al. (2016) used this approach, as well as data on the specific material contents of the various battery technologies to further quantify the environmental relevance of hazardous substances per battery type. As a result, the study clearly reveals that lead-acid batteries have a significant higher hazard potential compared to most Li-ion batteries[7].

These general findings need to be completed by management practices in Myanmar and the emissions caused by following practices:

As described in section 3.1, collection and recycling of lead-acid batteries takes place throughout the country. On the one side this means that large percentages of the embedded lead, lead-alloys and lead-oxide are recycled. On the other side the observed practices also result in significant emissions of sulfuric acid, as well as lead and lead-oxide mostly in the form of small particles (dust, sludge…). While these emissions mostly occur at scrap dealers, refurbishing workshops, battery breakers, as well as small scale and industrial smelters, the population of villages using SHS is mostly not directly affected by these emissions. Emissions mostly affect people working in related facilities, as well as persons living and working in nearby areas.

Although it is difficult to quantify related emissions, it can be assumed that almost all sulfuric acid contained in the batteries is released to the environment uncontrolledly. Furthermore, it is roughly assumed that around 5% of the lead contained in batteries is lost to the environment. With average lead-contents of 65% and average acid contents of 12.5% (Partners in Development 2009), this means that every year, between 1,440 t and 7,515 t of battery acid and between 374 t and 1,954 t of lead and lead-oxide are emitted to the environment of Myanmar from SHS batteries (average values: 4,478 t of acid, and 1,164 t of lead and lead-oxide).

As indicated in section 3.2, the Li-ion batteries used in SHS (LMO and LFP) are currently not collected and recycled. Due to the unfavourable economic situation for the recycling of these battery types, this situation is not likely to change fundamentally in the near or mid future. Thus, it needs to be assumed that LMO and LFP batteries will most likely be managed in parallel with other types of solid waste occurring in the places SHS are used. In rural Myanmar, municipal solid waste management systems are insufficiently developed or even absent. Organic waste is commonly disposed for composting or given to farm animals. Other types of household waste (e.g. packaging plastics) is reused or disposed / burned uncontrolledly. In this context, it is very likely that end-of-life LMO and LFP batteries will be disposed uncontrolledly in or close to villages using SHS. Some of the batteries might be given to repair and refurbishing operations in nearby towns as this was already observed in one case (see section 3.2.1). But also under this scenario, the batteries will sooner or later be disposed together with municipal waste. Thus, it can be concluded that without policy intervention the vast majority of LMO and LFP batteries from SHS will be disposed uncontrolledly.

[7] One exemption is lithium-nickel-manganese-cobalt batteries (LNMC) that show a comparable hazard potential to lead-acid batteries. Nevertheless, this battery technology has no relevance for SHS applications in Myanmar (see section 2.4).

5. Safety risks

Both, the use of lead-acid and Li-ion batteries are associated with some safety risks, which are summarized in the following sections.

5.1. Lead-acid batteries

Excessive charging of lead-acid batteries can cause electrolysis producing hydrogen and oxygen. This so-called *gassing* process can increase the inner pressure of the battery, which is normally released through valves. In case excessive pressure is not released (e.g. by valves joked with dirt), batteries might swell and finally explode. Such explosions are particularly risky because of the involved acid, which can cause severe damages to eyes and skin. The involved hydrogen can cause fires. In SHS in Myanmar, overcharging can occur in systems not using a charge controller. As indicated in section 2.2, this is the case in most consumer SHS.

5.2. Li-ion batteries

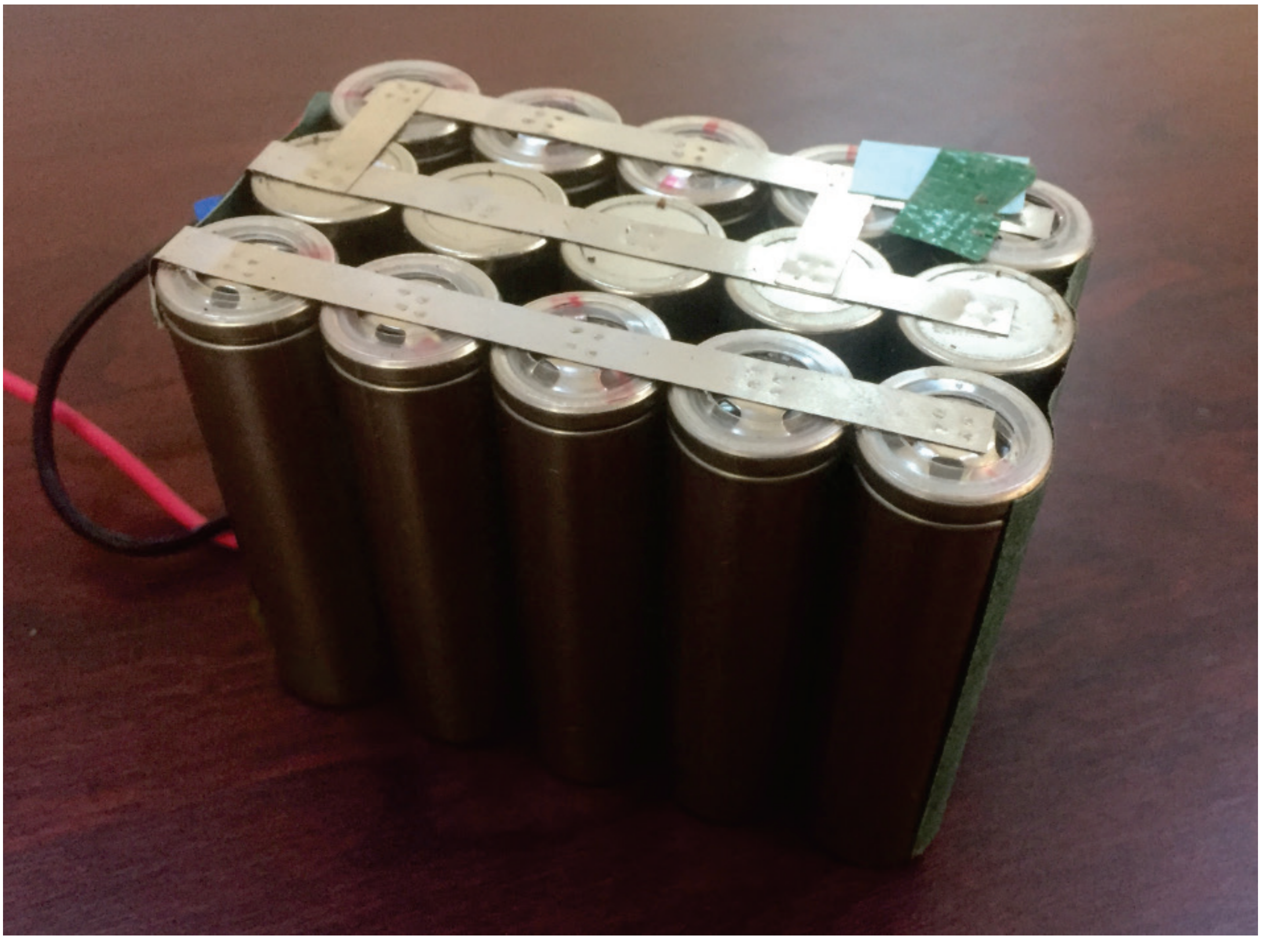
Overcharging, high temperatures and physical stress to battery cells can cause the so-called *thermal runaway*, which commonly leads to the destruction of the battery, fire and even explosions. In addition deep discharging can also cause battery fires. These processes are shortly described in the following:

- Overcharging and high temperatures can lead to the decay of the cathode material, which is a strongly exothermic reaction. The increasing temperature causes the organic electrolyte to evaporate, which leads to the formation of flammable gases. Deep discharging can also cause the evaporation of the organic electrolyte and the formation of flammable gases. In such a case, thermal runaway might start when a cell is charged: Due to the absence of electrolyte, the charging power is converted into heat, which can cause the decay of the cathode material and ignition of the contained gases (Mähliß 2012).
- Due to manufacturing errors (e.g. small accumulation of microscopic metallic particles, uneven separators), individual cells might be subject to short-cuts, overheating and the chemical and physical processes described above. While most manufacturers have very stringent quality controls to reduce such risks as much as possible, it must be assumed that less recognized manufacturers (e.g. producing for very price sensitive markets) have less stringent controls (Battery University 2018).

Generally, overcharging, deep discharging and physical stress do not necessarily lead to a thermal runaway. But wrong handling, exposure to high temperatures and physical stress can affect battery cells negatively, which can subsequently cause a thermal runaway even days and weeks after individual stress-peaks.

One problem of a thermal runaway is the risk of ignition of other neighbouring cells. Most battery packs contain several cells and the heat of one burning cell can easily trigger thermal runaways in neighbouring cells (see Figure 5-1).

Figure 5-1: Typical combination of Li-ion cells for a battery pack used in SHS



Source: Own photograph

There is an intensive debate on differences in fire safety of different types of Li-ion batteries. These debates usually refer to the following aspects:

- The decay of some cathode materials leads to the formation of oxygen, which fuels the battery fire from the inside. Thus, the cathode fire cannot be extinguished. This aspect applies to Li-ion batteries containing cobalt and has therefore no relevance for the batteries commonly used in SHS (LMO and LFP).
- Most cathode materials used in Li-ion batteries decay at temperatures between 180°C to 225°C (Hietaniemi 2015). The cathode material of LFP-batteries is thermally more stable and can resist temperatures of up-to 300°C (Kurzweil & Dietlmeier 2016).

For these reasons, LFP batteries are commonly referred to as those Li-ion batteries with the lowest fire risks. Nevertheless, other experts argue that differences are negligible and that all types of Li-ion batteries are associated with fire risks (EnBausa.de 2014).

As overcharging and deep discharging are major factors that can trigger thermal runaways, it is obvious that SHS using Li-ion batteries need to be equipped with suitable charge controllers. But as indicated in sections 2.2 and 2.3, SHS users in Myanmar are used to link PV-panels directly to batteries and do own repair attempts once individual SHS elements fail. These patterns present particular additional risks in this context. These risks can at least partly be mitigated by design strategies where the charge controller is closely attached to the battery cells (within one enclosure) and where warning signs clearly indicate that this enclosure should not be opened or manipulated.

Further additional risks might emerge from potential reuse and refurbishing attempts as this is already well developed with lead-acid batteries (see section 3.1.3) and probably already starting with Li-ion batteries (see section 3.2.1). It must be assumed that such reuse strategies will also operate on the level of individual cells, thus encompassing dismantling activities of battery packs and regrouping of cells into new assemblies.

Further risks can occur during end-of-life management of Li-ion batteries. Batteries with a residual charge of at least 30% can be subject to thermal runaway. As battery recycling relies on the accumulation and management of larger battery volumes, the thermal runaway of one cell can ignite other cells and cause larger battery fires damaging entire storage and recycling facilities, which already happened in various places worldwide. Over the last years, various strategies have been developed to avoid such chain reactions in recycling facilities and during bulk transports. Often, several of the following strategies are applied in parallel:

- Manual discharge of batteries. A full discharge of all cells can effectively minimize fire risks, but is also associated with labour costs. Discharging devices and processes need to make sure that workers may not be subject to electrical shocks.
- Prolonged storage (several weeks) to make use of self-discharge effects prior to transports.
- Storage in buckets / drums that are places in some distance from each other so that a fire in one bucket cannot ignite batteries in other buckets. This strategy is commonly applied in combination with embedding in sand (next point).
- Storage and transport of Li-ion batteries embedded in sand (in buckets or drums). In case of a thermal runaway, the developed heat is absorbed by the surrounding sand and produces a glass-like enclosure around the battery. This type of packaging is widely established as the main means for international transports.
- Permanent monitoring of temperatures in storage drums. In case of temperature increases, firefighting measures are taken immediately.

Further risks exist when Li-ion batteries with residual charge are falsely treated as lead-acid batteries. In particular when batteries are broken manually (see for example section 3.1.4), fires and explosions can seriously harm workers of such facilities.

6. Recycling of other SHS components

Although the batteries are usually the first SHS component to fail, other components (PV panel, charge controller, cables…) will at a certain point in time also become waste. Although recycling processes are available for all of these components, the actual collection and recycling largely depends on the economic and legal drivers that motivate or discourage the collection and recycling of those components. As there is no regulatory framework addressing the collection and recycling of e-waste in Myanmar yet (see chapter 7), net-material values and transport costs are largely decisive. Table 6-1 gives an overview on indicative scrap values of SHS components. It needs to be stressed that these prices are subject to variations over time and also strongly depend on the location as transport costs to recycling facilities are not factored in.

Table 6-1: Indicative scrap values of selected SHS components

SHS component	End-of-life value[8]	Data source	Comments
PV panel	-0.59 to -1.41 US$/kg	D'Adamo et al. (2017)	Transport costs to recycling plant are not included.
Charge controller & inverter	0.27 US$/kg	Precious-Metal-Services.com (2018)	German spot-market price of 24.01.2018. Transport costs to recycling plant are not included.
Cables	0.91 to 1.31 US$/kg	Precious-Metal-Services.com (2018)	German spot-market price of 24.01.2018. Transport costs to recycling plant are not included.

The data of Table 6-1 indicates that there the value of recoverable materials from PVC panels is insufficient to cover recycling costs. Coupled with the lack of a legislative framework demanding/motivating collection and recycling in Myanmar, it needs to be assumed that end-of-life PV panels will either be disposed uncontrolled or managed in parallel with municipal solid waste. On the other side, scrap prices for electronic components (charge controller) and cables are positive. Cables have a quite high positive value because of its copper content and therefore usually find their way to (copper) recycling. Here, one common problem is the removal of the cable insulation. While this is necessary for recycling purposes and will increase the scrap price, one common way of doing this are open cable fires. While cable fires cause significant emissions of persistent organic pollutants (POPs), the process does not require any investment costs or significant labour input and is therefore often preferred by many informal recyclers. Although, product design cannot fully avoid such processes and emissions, it is also known that cable fires are particular problematic with cables being insulated with halogen containing insulation material (e.g. PVC).

Although electronic components often achieve quite high scrap prices, the electronics used for charge controllers does not contain very high concentrations of precious metals. Therefore, scrap prices are in a range where the economic feasibility of collection and recycling largely depends on transport costs.

[8] Assuming environmentally sound processing/disposal.

7. Regulatory framework for waste management & recycling

7.1. Environmental Quality Guidelines

National Environmental Quality (Emission) Guidelines was ordered by the Government of the Republic of the Union of Myanmar Ministry of Natural Resource and Environmental Conservation (Notification No. 615 / 2015) Nay Pyi Taw, on the 3rd Waning Day of Nadaw, 1377 M.E. (29.12.2015). It is considered a part of the Environmental Conservation Law (2012), which allows the enactment of the national environmental quality guidelines by the Ministry. The new national-level Environmental Conservation law is planned in the future according to the Ministry of Information.

These National Environmental Quality (Emission) Guidelines (hereafter referred to as Guidelines) provide the basis for regulation and control of noise and vibration, air emissions, and liquid discharges from various sources in order to prevent pollution for purposes of protection of human and ecosystem health.

The Guidelines contain various benchmarks for emissions. If benchmarks for emissions are surpassed, an unspecified brief time is given to meet the benchmarks before monetary compensation, including suspension and shut-down could be imposed by the regulators. The time to meet the requirements also depends largely on local complaints and media acknowledgement on the issue.

The content of the guidelines is structured as follows:

- Chapter I (General Previsions)
- Chapter II (Implementation Procedures)
  - Annex 1 (Emission Guidelines)
    1. General Guidelines
    2. Industrial Specific Guidelines
       - 2.1. Energy Sector Development
       - 2.2. Agriculture, Livestock and Forest Development
       - 2.3. Manufacturing
       - 2.4. Waste Management
       - 2.5. Water Supply
       - 2.6. Infrastructure and Service Development
       - 2.7. Mining

7.2. Environmental Impact Assessments

To implement the Environmental Conservation Law, the Ministry of Natural Resources and Environmental Conservation (MONREC) has finalized an Environmental Impact Assessment (EIA) Procedure for guiding and supervising EIA proposed development projects. The latest version of the Procedure was dated 29 December 2015. The Procedure is comprehensive and covers not only the preparation and review of EIA documents including environmental management plans (EMP), but also the implementation of EMPs, including monitoring and reporting of environmental performance of the Project, and corrective and punitive actions to be taken by MONREC if the performance deviates from the related standards. The Procedure therefore covers requirements for all four basic management elements-plan, implement, monitoring and reporting, and control (or plan-do-check-act in the management cycle.

The Procedure has 11 chapters containing 131 articles or sections. The chapters are

1. Title and Definitions (Articles 1 and 2)
2. Establishment of the Environmental Impact Assessment Process (Articles 3 to 22)
3. Screening (Articles 23 to 30)
4. Initial Environmental Examination (Articles 31 to 43)
5. Environmental Impact Assessment (Articles 44 to 70)
6. Appeal Process (Articles 71 to 75)
7. Environmental Management Plan (Articles 76 to 82)
8. Environmental Consideration in Project Approval (Articles 83 to 105)
9. Monitoring (Articles 106 to 122)
10. Strategic Environmental Assessment (Articles 123 to 124)
11. Administrative Punishment (Articles 125 to 131)

7.3. National Waste Management Strategy

Myanmar's National Waste Management Strategy and Action Plan (NWMSAP) is the Government's first national initiative aimed at tackling waste. It offers a strategic guide for addressing key issues, opportunities and challenges associated with achieving a resource efficient and zero waste society. It is the result of the concerted and dedicated efforts of team led by the Director General of the Environmental Conservation Department (ECD) of the Ministry of Natural Resources and Environmental Conservation (MONREC) and comprised of the Director of ECD's Pollution Control Division. Various stakeholder groups have been involved in drafting the strategy. The National Waste Management Strategy and Action Plan is valid for the time period between 2017 and 2030 and currently available as final draft (Final Draft-Revised Version X of July 2017). The following content, still under revision process, describes:

1. Introduction to the strategy

   The introduction focuses on reform process in the industry and strategy to achieve national vision for resource efficient and zero waste society.

2. Strategy development: The process

   This strategy development process that led to this strategy involved roundtable consultation between Yangon City Development Committee (YCDC) and multi-stakeholders to discuss potential national strategies to identify key goals, objectives and action using quick study/baseline report.

3. Waste Management: Where we are now

   The geological, cultural and economic data are presented. This section focuses on waste generation and composition data for Yangon and Mandalay. It also outlines current waste management practices and technologies used for waste management by municipalities. The need for waste treatment technologies, land and facilities are addressed.

4. How to move forward

   Beside technologies, awareness & education plays a major part in future development. Waste management is part of the national growth strategy; current waste hierarchy priorities prevention, reduction, recycling, recovery and disposal, from most to least preferred (which is in-line with waste hierarchies defined in other world regions such as the EU).

5. Setting national goals, objectives and targets

   National goal is to reduce, reuse and recycle waste to the point where sustainable development can be reached. Efficient manufacturing, good environmental policy and monitoring programs will ensure a zero waste society. NWMSAP outlined 5 goals and set short, mid and long term targets.

6. Implementation priorities and mechanisms

   First, awareness and education are priorities in implementation. Financing mechanism and improving technologies are obstacles that need to be resolved.

7.4. Waste management policy in Shan State

The waste management policy in Shan State was ordered on February 5th, 2016 by municipal of Shan State Committee. The municipal will enforce the designated areas such as bins and waste disposal options. The Committee will review to provide more area for disposal, when necessary upon request, for new commercial or residential development. For biohazard waste disposal from hospitals (Article 21), the Committee will enforce the waste to be kept in the designated area with labelled colored bags (color to be specified by local municipal), and arrangements will be made to collect the waste. For Industrial chemical waste, the regulations require to dispose the waste systematically in separate designated bins. Specific labelling in different colored bags should be used; however, the law does not specifically state it for industrial waste. The disposers of such waste must pay monthly waste tax to municipal depending on waste content and quantity, and the Committee will determine regulations for disposal process after reviewing.

7.5. Green Economy Policy Framework

National Green Economy Policy and Strategic Framework aims at achieving green growth, climate resilience, inclusive and sustainable economic development in Myanmar. This policy is currently being drafted.

7.6. Hazardous Waste Management Masterplan

A Masterplan for Hazardous Waste Management in Myanmar has been drafted by MONREC in May 2017 and will be subject to wider consultation in 2018. In this drafting process, MONREC was supported by the Government of Norway (MONREC 2017).

Generally, the Masterplan aims at achieving a sustainable hazardous waste management system that effectively addresses current problems and that takes into account the future industrial development of Myanmar. To do so, the draft Masterplan applies / suggests the following principles that are in-line with common international good practices. The wording of the following list of principles is taken from the Draft Masterplan:

- Waste Hierarchy: The Waste Hierarchy is a strategic tool which prioritizes actions for waste management. This consists 3Rs including Reduce - reduce waste that must be generated and which goes to the landfill (this includes composting); Reuse – repair goods that can be repaired, or find alternative uses for wastes; Recycle - return wastes with recoverable value for re-processing.
- Management of hazardous wastes should be environmentally sound: This principle implies that the waste generation is reduced to a minimum; that adequate disposal facilities are available; that persons involved are adequately trained; that consequences in case pollution occurs are minimized; that Technical Guidelines are available for specific waste streams and waste treatment/disposal options.
- Resource conservation: Entails promoting the most efficient use of resources, including resource recovery and waste avoidance.
- Polluter-pays Principle: A principle that holds that those responsible for causing pollution or generating solid waste should pay the cost for dealing with the pollution, or managing the solid waste (collection and disposal) to maintain ecological health and diversity.
- Precautionary Principle: A principle that dictates that a lack of scientific data/information certainty should not be used as a reason for not acting to prevent serious or irreversible environmental damage or degradation.
- Proximity Principle: A principle that maintains that waste should be dealt with as close to the source of generation as possible. This reduces transportation costs, and reduces risks of contamination of the environment during transport.
- Principle of self-sufficiency: A principle implying that most waste should be treated or disposed of within the region in which it is produced.
- Least Trans-Boundary Movement Principle: A principle implying that Myanmar will follow the intention of the Basel Convention to the largest extent possible.
- Principle of Sovereignty: A principle implying that nothing in the Master Plan shall affect in any way the sovereignty of Myanmar over their territorial seas and their jurisdiction and the right in their respective exclusive.

In addition, the Draft Masterplan sheds light on various important aspects affecting current and future hazardous waste management in Myanmar, including regulatory and institutional frameworks, required elements of effective management systems, aspects to be specifically considered in the Myanmar context (e.g. the small generator problem) and a short compilation of facts for relevant hazardous waste streams in Myanmar. In this latter list, batteries and their associated challenges are missing. Nevertheless, waste electrical and electronic equipment (e-waste) is considered in an own sub-chapter.

8. Conclusion & recommendations

The high market penetration of solar home system (SHS) has important implications for the waste management and recycling situation in Myanmar. While the regulatory and organizational frameworks for solid and hazardous waste management are under development, there are not yet mature and environmentally sound management systems for most types of hazardous waste such as waste lead-acid batteries and other SHS components (e-waste). In addition, rural areas of Myanmar (where most SHS are being installed and used) widely refer to local waste disposal solutions such as composting of organic waste and burning/disposal of other wastes. In this context the equipment brought into villages with solar home systems (batteries, PV panels, controllers, inverters, lamps, TVs…) will sooner or later create new and demanding waste management issues. While some of the equipment has life-times > 5-10 years (e.g. PV panels), batteries are often the first component to fail. Coupled with the high toxicity potential of the most widely used lead-acid batteries, battery collection, recycling and disposal currently deserve highest priority amongst the various open disposal challenges around SHS.

In this context, the study revealed that – due to the high material value of the contained lead – most waste lead-acid batteries are in fact already channelled towards scrap dealers and recycling enterprises within and outside of Myanmar. While these market driven management activities effectively minimize the accumulation of hazardous battery waste in villages, the battery recycling and management chain has some severe shortcomings that lead to significant emissions of sulfuric acid, lead and lead-oxide.

While this situation calls for concerted regulation and improvements in the lead-acid battery recycling chain in Myanmar, this strategy might be coupled with the application of particular durable batteries (less battery waste over time) as well as SHS designs using less toxic Li-ion batteries such as LMO and LFP. Although this latter strategy element would in fact reduce the overall toxicity potentials of batteries, the following points need to be considered when referring to Li-ion batteries:

- There are currently no considerable collection and recycling activities for LMO and LFP batteries in Myanmar. This is due to the relatively low material value, the limited international recycling capacities and the logistical difficulties for storage and transport. This situation will most likely only change when a strong regulatory framework and a related financing system motivate collection and recycling activities. The net material values of batteries alone will be insufficient.
- Li-ion batteries might be subject to thermal runaways causing fires and explosions. In particular in rural houses that are often made from wood, such thermal runaways are a considerable safety risk. Thus, any SHS equipped with Li-ion batteries should use batteries and designs that effectively minimize these risks (see section 8.1 below).

Regarding improvement options, the activities and steps described in the following sections are recommended. While section 8.1 lays-out recommended criteria for the design of SHS and particularly subsidized SHS, section 8.2 presents short- and mid-term measures to stimulate lasting improvements in the lead-acid battery recycling chain. Lastly, section 8.3 describes potential mid- and long-term strategies towards a holistic strategy on e-waste that will largely depend on a regulative framework, a financing system, as well as technical and logistical capacities and monitoring ion the ground.

8.1. Design of Solar Home Systems

The design of (subsidized) Solar Home Systems should generally aim at

- a long lifetime of all system components in order to reduce the amount of generated waste;
- a material composition that avoids the use of hazardous and toxic substances;
- the reduction of safety risks (see chapter 5).

Specific criteria as well as corresponding international standards are listed in the next sections.

8.1.1. System requirements

In order to promote and distribute only Solar Home Systems with high durability, following quality standards shall be applied for the whole system:

Solar Home Systems must fulfil all criteria listed in the Solar Home System Kit Quality Standards by Lighting Global. Optionally the corresponding IEC Norm 62257: *Recommendations for renewable energy and hybrid systems for rural electrification* can be used to verify a sufficient system quality.

8.1.2. Battery requirements

As batteries often are the first SHS-component to fail, battery specific standards shall be met:

The batteries used in Solar Home Systems must in all cases comply with the battery specific criteria listed in the Solar Home System Kit Quality Standards by Lighting Global or optionally the corresponding IEC Norm 62257: Recommendations for renewable energy and hybrid systems for rural electrification.

This includes a minimum warranty period from the time of purchase by the end-user of at least two years. Lithium batteries must additionally carry UN 38.3 certification and have overcharge protection for individual cells or sets of parallel-connected cells.

In addition to that, following criteria shall be met:

- The quality of batteries shall comply with IEC 61427: Secondary cells and batteries for renewable energy storage – General requirements and methods of test – Part 1: Photovoltaic off-grid application. The required cycling endurance tests have to be conducted in accordance with the applicable standard for each battery chemistry, e.g.:
  - *IEC 60896-21: Stationary lead-acid batteries – Part 21: Valve regulated types – Methods of test*
  - *IEC 61056-1: General purpose lead-acid batteries (valve-regulated types) – Part 1: General requirements, functional characteristics – Methods of test*
  - *IEC 61960: Secondary cells and batteries containing alkaline or other non-acid electrolytes – Secondary lithium cells and batteries for portable applications*

  If cycle life testing is not possible for reasons of time-constraints, the batteries have to fulfill at least the above listed quality standards according to Lighting Global or optionally the corresponding *IEC Norm 62257.*
- If Lithium Ion batteries are used, the safety requirements defined in *IEC 62133: Secondary cells and batteries containing alkaline or other non-acid electrolytes – Safety requirements for portable sealed secondary cells, and for batteries made from them, for use in portable applications – Part 2: Lithium* systems must be met.

- In order to avoid improper treatment by the end-user, Li-ion battery cells and charge controller must be encased in one common housing that cannot be opened with commonly available tools such as screwdrivers. Appropriate warnings (in English and local language) have to discourage any manipulation of this battery housing and must indicate associated risks (electric shocks, fires and explosions). Warning signs must be clearly visible and might use a warning text such as “Do not open or manipulate the battery unit. Manipulation may cause electric shocks, fires and explosions”. In addition, the housing must clearly indicate the type of battery (Li-ion).

The existing safety requirements for Lithium Ion batteries defined in IEC 62133 are currently not customized for batteries used in Solar Home Systems. Instead they are aligned to fit portable applications as for example batteries in mobile phones. Therefore, updates in the battery standard landscape should be checked on a regular basis.

8.1.3. Material requirements

In order to minimize negative impacts on the environment, substances with especially critical properties shall be banned from being used in SHS equipment wherever possible and economically feasible. The following requirements effectively ban the use of lead in solder paste of electrical and electronic assemblies, as well as the use of PVC in cables. Both are known to cause environmental problems in uncontrolled recycling and disposal (see also chapter 6). The first set of criteria is coherent with RoHS regulations in the EU that uses the same set of benchmarks for the six addressed substances in electrical and electronic equipment[9]. Similar restrictions are in the Korean RoHS and the China RoHS also include similar specifications.

Electrical and electronic components and assemblies, such as charge controllers, inverters, printed circuit boards, interfaces and solder pastes, shall not contain the following substance above the specified concentration value tolerated by weight in homogeneous materials:

- Less than 0.1% of lead (Pb), mercury (Hg), hexavalent chromium (Cr+6), polybrominated biphenyls (PBB), polybrominated diphenyl ethers (PBDE),
- Less than 0.01% of cadmium (Cd)

These requirements do not apply to batteries[10] and PV panels[11] which are excluded from the scope of the RoHS Directive.

Furthermore, all plastic parts > 25 g used in SHS and cables shall meet the following requirements:

Plastic parts > 25 g and all cables shall not contain halogenated polymers. This also includes halogenated organic compounds that are sometimes added as flame retardants.

Pollution problems may also result from unsound disposal and recycling of PV panels that may contain hazardous substances such as lead and cadmium. Nevertheless, there is currently insufficient information on the types and material composition of PV panels used in SHS in Myanmar and the technical and economic feasibility of phasing-out certain pollutants from such panels.

[9] Starting 22th of July 2019, the EU RoHS Directive will further limit the use of Bis(2-ethylhexyl) phthalate (DEHP), Butyl benzyl phthalate (BBP), Dibutyl phthalate (DBP), Diisobutyl phthalate (DIBP). Thus, these specifications might have to be adjusted accordingly in 2019.

[10] Batteries are regulated by the Batteries Directive 2006/66/EC and thus excluded from RoHS under recital 14.

[11] PV panels are excluded from the scope of the RoHS Directive through Article 2(4)(i).

8.2. Improve the recycling chain of lead-acid batteries

Recycling of lead-acid batteries is – from a pollution and health and safety perspective – an outstandingly critical industrial process. Lack-of health and safety measures as well as pollution control inevitably cause severe detrimental effects on human health and the environment and will create highly problematic legacies. For this reason, unsound ULAB recycling was classified as one of the world's worst polluting industries (Green Cross & Pure Earth 2016) and addressed by resolution UNEP/EA.3/L.24 passed by the United Nations Environment Assembly (UNEA) in December 2017 (United Nations Environment Assembly 2017). Experiences from various countries and world regions have shown that improvements strongly depend on stringent government regulation and monitoring: It is essential that the ULAB recycling industries of a country are challenged with the same ambitious minimum standard. This standard should be clearly communicated, enforced and non-compliance should be sanctioned with temporary closure or withdrawal of operating license. The application of one uniform standard and ambition level is important because low-standard facilities are often more profitable compared to high-standard facilities and can therefore offer quite attractive prices for waste lead-acid batteries. In such situations, it is likely that low standard facilities will sooner or later rule-out competitors that invest in higher environmental standards. Thus, the absence of ambitious standards and related enforcement activities automatically favours worst performers.

Regarding the situation in Myanmar, it is recommended to co-operate with the relevant authorities such as the Ministry of Natural Resources and Environmental Conservation (MONREC) and the Ministry of Industry in order to address the existing challenges. Amongst others, the following steps are suggested:

- **Stakeholder Workshop** on environmental and health effects of lead-acid battery recycling: The workshop should present key findings from this study as well as information on commonly practiced unsound processes and their impacts, best-practices, economic considerations and improvement options. The workshop should also highlight and discuss the need for stringent regulatory oversight over lead recycling industries and should highlight the need for follow-up activities.
  - Aim: Generate an understanding of the potential environmental and health impacts of unsound lead-acid battery recycling and the importance of standards and enforcement. Generate an agreement amongst key stakeholders that the issue should be followed-up by the relevant authorities and in further consultations with key stakeholders.
  - Target groups: Decision-makers from government, industry and civil society organizations. In addition: Key actors in the field of rural electrification and solar home systems.
- **Developing a roadmap for improvements** by relevant authorities and in consultation / dialogues with selected stakeholders (e.g. recycling enterprises, city administrations of Yangon and Mandalay)
  - Aim: Coordination between government agencies, clarification of responsibilities, definition of strategy and next steps.
  - Target groups: Relevant authorities such as MONREC, the Ministry of Industry and DRD.

- **Training of auditors** from authorities such as MONREC and possibly also third party auditors for evaluating the environmental and safety performance of lead-acid battery recycling facilities with reference to international best-practices and guidelines.
  - Aim: The training should enable around 20 individuals to independently assess lead-acid battery recycling facilities and to formulate clear and concise recommendations and improvement plans on a facility level. With these skills the individuals will qualify as auditors for lead-acid battery recycling facilities.
  - Target groups: Auditors in charge of factory inspections, including environmental and health audits.
- **Baseline Audits** to all major lead-acid battery recycling facilities should be conducted in a joint effort between the newly trained auditors and one or more international auditors.
  - Aim: The baseline audits will be a first practical experience for the newly training auditors. In addition the outcomes of these baseline audits should be used for drafting facility-level improvement plans. Ideally, these improvement plans are backed by the government authorities and tied to clear timelines and sanction mechanisms.
  - Target groups: Lead-acid battery recycling enterprises, newly trained auditors, relevant authorities.
- **Follow-up & regular monitoring** to verify companies' progress and the implementation of improvement plans. I the case of non-compliance with improvement plans, application of sanction mechanisms.
  - Aim: Transition to ambitious and constant enforcement mechanism.
  - Target groups: Lead-acid battery recycling enterprises, trained auditors, relevant authorities.

8.3. Develop regulative framework and incentive system for sound collection and recycling of e-waste

As indicated in chapter 6 and section 3.2.1, many SHS components (including Li-ion batteries) have material values that are insufficient to motivate specific collection and recycling activities and will therefore most likely be disposed-off in parallel to municipal solid waste. Due to the various hazardous substances and recyclable raw materials contained in e-waste, such disposal is internationally considered as environmentally unsound. In addition, some fractions that do have enough material value will – in case there are enough quantities – most probably be recycled in a highly polluting manner (e.g. the open burning of cables to recover copper). These unsound disposal and recycling patterns do not only have relevance for SHS equipment, but also for other types of electrical and electronic equipment that is sold and used in Myanmar in rapidly increasing quantities.

Thus, it is recommended to address the issue in parallel to attempts to organize a modern and effective e-waste collection and recycling system in Myanmar. While e-waste aspects are already shortly sketched in the Draft Hazardous Waste Management Masterplan (see section 7.6), there is not yet any specific policy, regulation or financing instrument on e-waste management in Myanmar.

In this context, it needs to be mentioned that establishing a modern e-waste management system is a demanding task that usually requires the involvement of various authorities and stakeholders and usually takes several years from the start of related policy debates. As it is impossible to come-up with a clearly defined roadmap for such a process, the following points highlight issues that should be considered in such processes:

- Although some e-waste types contain valuable raw materials such as copper, other e-waste types and components have a low value or might even be associated with negative values (costs for sound disposal). Therefore one key challenge is to design a financing mechanism that covers the costs for collection and environmentally sound recycling of e-waste.
- Such financing mechanisms are usually based on the principle of Extended Producer Responsibility (EPR) that says that companies that place e-equipment onto the market (e.g. producers, importers) should be held responsible for sound collection and recycling.
- This responsibility can be translated into different types of financing systems: Either by demanding producers and importers to organize collection and recycling themselves (or in a group of companies – often referred to as “Producer Responsibility Organization”), or by contributing to a fund earmarked for sound collection and recycling.
- Such EPR strategies require a legal base and therefore depend on a national law or regulation specifying the above mentioned responsibilities and implementing mechanisms.
- In any case, EPR-based e-waste policies require a careful monitoring (e.g. on use of funds, the collected and recycled volumes, the environmental performance of recyclers) and probably also adaptation.

The points above illustrate the complexity of the involved tasks, which probably overstretches the scope of rural electrification projects. Thus, related efforts by rural electrification projects should probably seek co-operation with other projects and policy initiatives. Amongst others, it should be considered to bring-in points around battery and e-waste recycling into the ongoing consultation process related to the Hazardous Waste Management Masterplan.

It should also be considered to start pilot activities related to the collection and recycling of SHS equipment and e-waste from rural communities: Such pilot activities could aim at the collection and sound recycling of a defined quantity of e-waste (e.g. the equivalent amount to the SHS equipment installed by a project). While such pilot activities can support the kick-start of sound collection and recycling activities, they can also provide important experiences and lessons-learned for e-waste related policy development.

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